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NAS REPORT ON TECHNOLOGICAL FEASIBILITY OF 1975-76 MOTOR VEHICLE EMISSION STANDARDS

MANUFACTURABILITY AND COSTS OF PROPOSED LOW-EMISSION AUTOMOTIVE ENGINE SYSTEMS

NATIONAL ACADEMY OF SCIENCES

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

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The Panel examined and reported the status of four domestic auto manufacturers' catalyst manufacturers' production plans for 1975/76 emission control system. Also examined was the potential production status of rotary, Diesel, and stratified charge engines. The Panel also provided an estimated resource impact of 1976 emission control systems.

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MANUFACTURABILITY AND COSTS OF PROPOSED LOW-EMISSION AUTOMOTIVE ENGINE SYSTEMS

Report by the

Panel on Manufacturing and Producibility

to the

COMMITTEE ON MOTOR VEHICLE EMISSIONS

NATIONAL ACADEMY OF SCIENCES

January 1973

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NOTICE

The Committee on Motor Vehicle Emissions has evaluated the technological feasibility of meeting the light-duty motor vehicle emissions standards as prescribed by the Clean Air Amendments of 1970. This study was performed under the sponsorship of the National Academy of Sciences and with the express approval of the Governing Board of the National Research Council.

The Committee obtained much of its information from eight panels of consultants, each panel dealing with a particular subject area of importance in the Committee deliberations. Panel members were selected by the Committee on the basis of recognized competence in specific areas.

The panel reports are reports of the panels to the Committee. Before publication, each panel report was reviewed by appointed members of the Committee. The views represented by the panels are one of the sources of information provided to the Committee and were used as a partial basis for the Committee judgments.

PREFACE

In legislating the Clean Air Amendments of 1970, the Congress asked the Environmental Protection Agency to contract with the National Academy of Sciences to conduct a comprehensive study and investigation of the technological feasibility of meeting the motor vehicle emissions standards prescribed in accordance with the law. In responding to this request, pursuant to a contract with the Environmental Protection Agency, the Academy established a Committee on Motor Vehicle Emissions and charged it with the conduct of this study. The Committee published the results of its work in a report to the Environmental Protection Agency dated February 12, 1973.

As means of providing itself with authoritative information and expertise in the various critical aspects of the problem it undertook to study, the Committee appointed specialist panels to undertake investigations and report their findings. The following report, Manufacturability and Costs of Proposed Low-Emission Automotive Engine Systems, presents the findings of one of those panels.

Taken together, the special panel reports constitute a very substantial accumulation of data and analysis brought together by many specialists in many investigations in a very fast-moving area of technological development. In its published report, the Committee on Motor Vehicle Emissions has, of course, brought together that part of all this information and analysis required to fulfill its stated obligation to the Environmental Protection Agency. The separate reports of the specialist panels are published for the public record and to complete the documentary record.

Eleven appendixes are referenced in the body of this report. These appendixes are being published in a separate volume.

Chapter 9 of the panel report presents an estimated impact on resources that would be caused by introducing new engines according to an assumed implementation plan. After the final draft of the report was approved by the panel members, the Committee asked that a similar program be run for a different implementation plan. This work was done almost entirely by Mr. LeRoy Lindgren, and thus it is presented here as a separate "Supplementary Report" with Mr. Lindgren as the sole author.

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1 INTRODUCTION

On August 11, 1971, a panel of five professional consultants was convened in Washington, D.C., to advise the Committee on Motor Vehicle Emissions on the producibility and cost of automotive emissions hardware. This committee, designated the Panel on Manufacturing and Producibility, was charged with the assessment of the capability of the automotive industry to produce hardware to meet the 1975 and 1976 requirements of the Clean Air Amendments of 1970 and to determine the associated manufacturing costs.

An extensive program of visits was carried out to gather information on these questions (see Appendix I).* A Status Report, responsive to its charge, was issued on December 15, 1971 (see Appendix II). The charge to the Panel was extended on January 11, 1972 (Appendix III). A progress report was subsequently issued on the effort to May 26, 1972 (Appendix IV), and also a reply to a question from catalyst manufacturers (Appendix V). Included in the work of the Spring was a review of the use of liquefied gas substitutes for gasoline (Appendix VI). The major efforts by the Panel during the summer of 1972 were (a) visits to U.S. Diesel manufacturers (Appendix VII), (b) a two-week series of visits to manufacturers in England and on the Continent (Appendix VIII), (c) a visit to General Motors on the Wankel engine (Appendix IX), and (d) revisits to the American automobile companies on their progress on hardware for emissions control for 1975 and 1976 (Appendix X). With the potential proliferation of automobile engines, a simulation model was used by the Panel to assess the impact on national manufacturing resources of a diverse mixture of engines (Appendix XI). Although this report is based on the information gathered by the Panel from its inception, the activities of the Panel in 1972 do receive special emphasis.

It was not the function of this Panel to determine the acceptability of any configuration to meet the 1975-1976 standards. Our function was to assess production capabilities and determine costs for those

* The appendixes to this report are bound in a separate volume.

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configurations that are serious production possibilities for American automobile production. We wish to especially disclaim any implication of the acceptability of any configuration to meet the 1975-1976 standards.

2 STATUS OF 1975/1976 MODELS FOR UNITED STATES AUTOMOBILE COMPANIES

The United States automobile companies manufacturing plans for the 1975-1976 configurations are not firm at this stage. Further changes will almost certainly be made between now and the start of production, but each company has taken positive steps toward the implementation of their best present estimate of the components that might be introduced for 1975. Some companies have anticipated changes and have incorporated these changes into current 1973 models. The schedules are compressed and significant risks are involved. Consequently, most companies have more than one alternative plan for 1975. In fact, in some cases they have even designed and made tooling for alternative configurations.

United States automobile manufacturers are capable of mass producing 1975 model vehicles with the power plant and emission devices configuration that has been and is the preferred design. The declaration by General Motors that they will manufacture monolith catalysts for themselves and others removes the last important barrier to providing components in time.

During the past year a configuration including a single element combined oxidation-reduction catalyst and a computer-controlled fuel injection system has become a possibility to meet the 1976 Standards. The capability exists to mass produce this for the 1976 models. Monolith catalysts are expected to be required and facilities for their production now seem assured.

A major element contributing to uncertainty in the final configuration is the long time (approximately four months) required to complete 50,000-mile testing. Several major decisions have to be made in the Fall of 1972 by all of the automobile companies in which they have to commit themselves to tooling and the purchase of materials for 1975-1976 cars: buildings, equipment and supplies for catalysts, and catalyst substrates.

GENERAL MOTORS

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General Motors has made the most apparent progress, in our opinion, toward the implementation of their manufacturing plans. They have not made the major commitments for some of the critical components but they had made investments in temporary tooling that would fulfill the production requirements of the 1975 model year and some of the 1976. They also have alternative configurations that will be developed in parallel until one or the other is a certainty as far as performance and maintenance is concerned. It is possible that several designs may be used in 1975 model cars, depending on the car size. The body changes related to the emissions control devices will be introduced in the United States in the next two years in order to be prepared for either configuration. General Motors has planned to produce air pumps for other manufacturers and has expanded their facilities to meet an expanded demand. They have production plans for electronic ignition and control hardware for both the 1975 and 1976 configurations. General Motors has manufacturing plants planned for a major effort to produce their own catalytic converter assemblies with their own monolithic substrates and their own catalyst specifications. General Motors plans to extrude the monoliths and cut them off to size rather than construct them by the rolled-paper process. A major effort is presently in process to determine the optimum way to deliver the proper fuel-air mixture to the combustion chamber.

FORD

The Ford Motor Company is currently testing several alternative configurations for 1975, although the crisis in certifying the 1973 models has substantially detracted from the 1975 development. The one major decision that Ford has made is to drop the thermal reactor, even though there are some thermal reactor configurations still being tested. This decision was anticipated in the Panel Status Report of December 15, 1971.

Ford has made funding commitments to catalytic converter companies such as Engelhard. (Engelhard will produce 60 percent of Ford's catalytic converters for 1975.) The Ford Motor Company's critical items include the catalyst and the "thermal carburetor."* They have dropped their manufacturing and engineering plans for the variable venturi carburetor. Ford will introduce electronic hardware for ignition and possibly controls of EGR. The body changes are being phased into the car body schedule so that they are on schedule as far as these are concerned. Many of the problems that they related a year ago have been resolved, such as vacuum loss, over-heating of the engine (with larger radiators), and burnt valve seats (by induction hardening). Changes will be required in engine components, production lines, and in the foundries.

CHRYSLER

The Chrysler Corporation is following its original implementation plan very closely. The only change in plans has been the elimination of the thermal reactor. It too has the same problems with the critical items such as catalysts, but it appears to have solved its carburetor problems. Chrysler is following both the pellet and the monolith catalytic designs so that it can be prepared to implement the design that gives the best test results. The Chrysler Purchasing Group has related that the noble metal sources have given them difficult negotiation problems because Chrysler directed much of its original design toward using base metal catalyst and then opened negotiations for noble metal catalysts at a serious bargaining disadvantage. Chrysler is introducing electronic fuel control, electronic EGR controls, and electronic spark advance in some of their 1975 models. These devices are planned across the line in the 1976 models.

*The combination of a new carburetor with a fast vaporization stove.

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AMERICAN MOTORS

American Motors has made arrangements (with the approval of the United States government) to depend on General Motors research and development in supplying them with the General Motors parts and equipment necessary to comply with the air pollution standards. Because of this, American Motors is closely tied to General Motors developments and is so vendor-dependent that there was no need for the Panel to update the status of its implementation with American Motors. As we travelled we found that the vendors were including American Motors in their volume plans. The decision of the Panel not to revisit American Motors was further justified by a recent revisit by the Panel on Emission Control Systems, which established that no major new programs or innovations had occurred since this Panel's last visit.

3 STATUS OF CATALYST MANUFACTURERS' PRODUCTION PLANS

Many of the catalyst manufacturers who are considered to be potential sources of catalysts for the automotive industry have been visited and their operations studied. The catalyst manufacturers who propose pelletized catalysts already have the sources for a substantial portion of the carrier materials and some capacity for coating with the active material. This type of catalyst is used extensively in the petroleum industry. The manufacturing facilities need only to be increased or additional similar type of equipment provided.

Many companies are active in the development of catalysts and substrates. The major source of monolithic catalytic carriers has been American Lava. Corning Glass Company has had a large research program to develop alternative methods of making the monolith carriers. General Motors has disclosed that they have developed an extrusion method for making monolith catalyst carriers. They have plans for constructing these facilities and have indicated their intention to become major emission control catalyst manufacturers including the carrier containers and possibly the active material itself that is coated on the carrier.

The previous reports by this Panel (see Appendix II) were concerned with oxidation catalysts primarily. Reduction catalysts for use in reducing NO_x are being developed. From a manufacturing viewpoint, the problems of producing oxidizing and reducing catalysts are the same. Examples of companies active in this field are Johnson-Matthey, Gulf, ICI, and UOP. For practical purposes, the catalysts fall into two categories. One is primarily a reduction catalyst, which is placed in the exhaust system ahead of the oxidation catalyst. The other catalyst is a single catalyst, which at stoichiometric composition of exhaust gas will oxidize and reduce simultaneously. The latter type is becoming increasingly attractive because of new electronic devices that make it possible to control the fuel-air ratio to the engine, and subsequently the exhaust is controlled in an exact manner that will match the capability of the catalyst.

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It has become increasingly apparent that 1976 catalysts will require the use of large quantities of rare metals such as platinum, palladium, and possibly ruthenium. During the visit to Johnson-Matthey, who sell about 70 percent of the free-world's supply of platinum and palladium compounds, the Panel was told that the required amounts of platinum can be available to meet the production schedules if decisions are made early enough. It is estimated that the value of the platinum in a converter will range from $4 to $6. They indicated that the time for building the necessary plants and opening the necessary mines was at hand during our visit in June and that postponement would cause increasing difficulties with delivery. The motor companies have delayed decisions because of the very large commitments for opening mines and having new plants built.

Experimental work on oxidation, reduction, and combination catalysts is proceeding at an increasing rate. The entrance of General Motors into the field of catalyst manufacturers makes it more probable that there will be sufficient substrates available at the proper time.

4 SUMMARY OF AUTOMOTIVE EMISSION EQUIPMENT DEVELOPMENT AND PROJECTION TO 1976 MODEL YEAR

In response to California and Federal regulations, the automotive industry has progressively added to their emissions control devices. The pattern of hardware additions is shown in Table 1. The hardware indicated through 1974 is largely committed at present. For the 1975 model year, the hardware has changed but little in the period December 1971 to September 1972 (see Panel Report of December 15, 1971).

The corresponding increases in sticker price associated with this hardware are detailed in Table 2 and summarized in Table 3. The cumulative increase is $259 through the 1975 model year, with $138 of this amount coming in 1975.

For the 1976-model year, a study of the work performed by the industry in the United States shows that, although they were working independently, there were many similarities in approach and, therefore, a most common configuration could be developed. The basis for this commonality was the determined effort by the industry to save as much of the technology of the carbureted internal combustion engine as possible. This configuration is described by component in Table 1 and is shown schematically in Figure 1.

The increase in sticker price for the 1976 "Most Common" configuration is detailed in Table 2 and summarized in Table 3. According to our estimate, the additional increase of the 1976 model year configuration over that for 1975 is $134, or about the same increment as for the 1975 model year configuration over that for 1974.

After careful study of the variables being considered by companies throughout the world, consideration was given as to what could be an attractive alternative to the main thrust the United States auto industries had developed in the control of the 1976 configuration. It is our considered opinion that the carburetor will be modified temporarily to meet the vaporization requirements but that fuel injection features more precise controls and lower maintenance costs and will provide lower

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Table 1

Chronology of Development of the Dual-Catalyst System

Model Year		Emission Hardware Added
1966	a)	PCV Valve
1968	a)	Fuel-Evaporation Control System
1970	a)	Retarded Ignition Timing
	b)	Decreased Compression Ratio
	c)	Increased Air/Fuel Ratio
	d)	Transmission-Control System
1972	a)	Anti-Diesel Solenoid Valve
	b)	Thermostatic Air Valve
	c)	Choke-heat Bypass
1973	a)	Exhaust-Gas Recirculation
	b)	Air-Injection Reactor
	c)	Induction-Hardened Valve Seats
	d)	Spark Advance Control
	e)	Air Pump
1974	a)	Precision Cams, Bores, and Pistons
Model Year		Emission Hardware-Likely Configuration
1975	a)	Proportional Exhaust-Gas Recirculation
	b)	Carburetor with Altitude Compensation
	c)	Air/Fuel Preheater
	d)	Electric Choke
	e)	Electronic Ignition
	f)	Improved Timing Control
	g)	Oxidizing Catalytic Converter
	h)	Pellet Charge
	i)	Increased Cooling System
	j)	Improved Underhood Materials
	k)	Body Revisions
Model Year		Most Common Configuration
1976	a)	NO_x Catalytic Converter, 2 required
	b)	Electronic Emissions Control
	c)	Sensors

Table 2

Estimates of Sticker Prices for Emissions Hardware from 1966 Uncontrolled Vehicle to 1976 Dual-Catalyst System*

Model Year	Configuration	Value Added[1]	Tooling Amort.[2]	Dealer Margin[3]	Profit[4]	List Price	Excise Tax[5]	Sticker Price
			TYPICAL EMISSIONS HARDWARE					
1966	PCV-Crank Case	1.90	-	.66	.29	2.85	.15	3.00
1968	Fual Evaporation System	9.07	.45	3.30	1.43	14.25	.75	15.00
1970	Carburetor A/F Ratio	.61	.02	.22	.10	.95	.05	1.00
	Compression Ratio	1.24	.03	.44	.19	1.90	.10	2.00
	Ignition Timing	.61	.02	.22	.10	.95	.05	1.00
	Transmission Control System	2.49	.05	.88	.38	3.80	.20	4.00
						Total 1970		8.00
1971 1972	Anti-Dieseling Solenoid	3.07	.10	1.10	.48	4.75	.25	5.00
	Thermo Air Valve	2.49	.05	.88	.38	3.80	.20	4.00
	Choke Heat By-pass	2.74	.05	.97	.42	4.18	.22	4.40
	(Assembly Line Tests Calif) (1/10 Volume)	.18	.20	.13	.06	.57	.03	.60
						Total 1971-72		14.00

Table 2 (Cont'd)

Model Year	Configuration	Value Added[1]	Tooling Amort.[2]	Dealer Margin[3]	Profit[4]	List Price	Excise Tax[5]	Sticker Price
1973	OSAC (Spark Adv. Control)	.48	.15	.22	.10	.95	.05	1.00
	Transmission Changes (Some Models)	.63	-	.22	.10	.95	.05	1.00
	Induction Hardened Valve Seats (4 and 6 cyl.)	.72	.55	.44	.19	1.90	.10	2.00
	EGR (11-14%) Exhaust Recirculation	5.48	.87	2.20	.95	9.50	.50	10.00
	Air Pump--Air Injection System	27.16	1.80	10.03	4.33	43.32	2.28	45.60
	(Quality Audit Assembly Line) (1/10 Vol.)	.23	.02	.09	.04	.38	.02	.40
						Total 1973		60.00
1974	Induction Hardened Valve Seat V-8	.72	.55	.44	.19	1.90	.10	2.00
	Some Proportional EGR (1/10 Vol. @ $52.)	3.21	.10	1.14	.49	4.94	.26	5.20
	Precision Cams, Bores, and Pistons	2.44	.10	.88	.38	3.80	.20	4.00
	Pretest Engines -- Emissions	1.80	.10	.66	.29	2.85	.15	3.00
	(Calif. Catalytic Converter System - 1/10 Vol. $64.)	4.02	.04	1.41	.61	6.08	.32	6.40
						Total 1974		20.60

Table 2 (Cont'd)

Model Year	Configuration	Value Added[1]	Tooling Amort.[2]	Dealer Margin[3]	Profit[4]	List Price	Excise Tax[5]	Sticker Price
1975	**Proportional EGR (accel-decel)	20.07	-	6.95	3.00	30.02	1.58	31.60
	New Design Carburetor with Altitude Compensation	7.52	2.00	3.30	1.43	14.25	.75	15.00
	Hot Spot Intake Manifold	2.87	.30	1.10	.48	4.75	.25	5.00
	Electric Choke (element)	2.67	.50	1.10	.48	4.75	.25	5.00
	Electronic Distributor (pointless)	4.35	2.00	2.20	.95	9.50	.50	10.00
	New Timing Control	1.40	.50	.66	.29	2.85	.15	3.00
	Catalytic--Oxidizing-Converter	18.86	4.00	7.92	3.42	34.20	1.80	36.00
	Pellet Charge 6# @ $2.00/lb	12.00	1.72	4.75	2.05	20.52	1.08	21.60
	Cooling System Changes	1.17	.10	.44	.19	1.90	.10	2.00
	Underhood Temp. Materials	.63	-	.22	.10	.95	.05	1.00
	Body Revisions Welding Presses	.67	.60	.44	.19	1.90	.10	2.00
	Assembly Line Changes	.13	.50	.22	.10	.95	.05	1.00
	End of Line Test Go-No Go	1.85	.05	.66	.29	2.85	.15	3.00
	Quality Emission Test	1.22	.05	.44	.19	1.90	.10	2.00
						Total 1975		138.20

Table 2 (Cont'd)

Model Year	Configuration	Value Added[1]	Tooling Amort.[2]	Dealer Margin[3]	Profit[4]	List Price	Excise Tax[5]	Sticker Price
		1976 MOST COMMON CONFIGURATION						
1976	2 NO_x Catalytic Converters	22.00	2.76	8.58	3.71	37.05	1.95	39.00
		22.00	2.76	8.58	3.71	37.05	1.95	39.00
	Electronic Control	28.00	3.75	11.00	4.75	47.50	2.50	50.00
	Sensors	3.00	.81	1.32	.57	5.70	.30	6.00
						Total 1976		134.00

Notes to Figure

1. Either value added or hardware cost, including material, labor overhead and G & A.
2. Tooling and equipment amortized over three years.
3. As 22% of selling price.
4. As 10% of list price.
5. As 5% of sticker price.

Costs are the average for the various car sizes and production volume for each size.

*Estimates based on 1972 dollars

**Proportional EGR costs were adjusted based on recent data

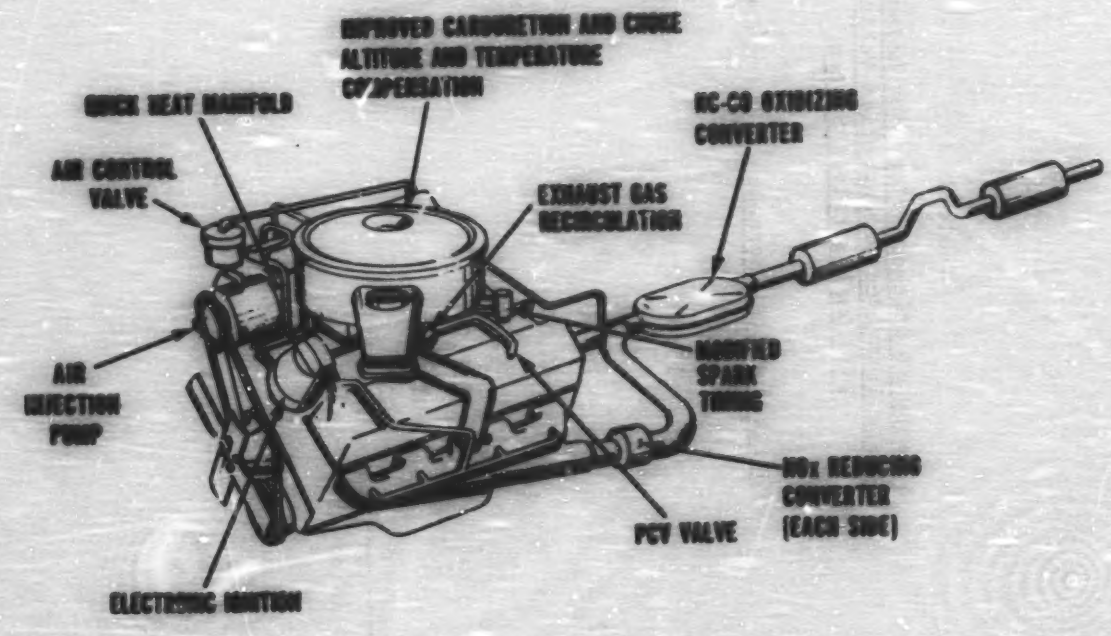
Table 3

Summary of Sticker Prices for Emissions Hardware from 1966 Uncontrolled Vehicle to 1976 Dual-Catalyst System

Year	Sticker Price Increase	Cumulative Price
1966	$ 3.00	$ 3.00
1968	15.00	18.00
1970	8.00	26.00
1971-72	14.00	40.00
1973	60.00	100.00
1974	20.60	120.60
1975	138.20	258.80
1976	134.00	392.80

1972 Dollars

FIGURE 1 TYPICAL DUAL-CATALYST SYSTEM



emissions throughout the life of the car. Fuel injection, restoring the fuel economy and driveability, controls the air-fuel ratio so that one can utilize a single converter to accomplish both control of HC/CO and NO_x. Combined with EGR and electronic controls, a single 3-way catalyst system can be used. The addition of more sophisticated electronic controls will assure car owners that the systems can maintain the desired control of emissions without excessive maintenance. These electronic devices will also provide the basis for future computer diagnostic systems for monitoring cars on the end of the assembly line and in use.

In summary, this "attractive alternative" approach in comparison with the carbureted engine provides (1) lower initial cost, (2) greater fuel economy, (3) improved driveability, (4) lower overall emissions in the lifetime of the car, and (5) lower maintenance costs.

The following table indicates the costs of the various components in this system:

BREAKDOWN OF INCREASED STICKER PRICE FOR FUEL-INJECTION FEEDBACK-CONTROLLED ALTERNATIVE CONFIGURATION

Item	Sticker Price Increase*
Fuel injection	$ 46
Electronic ignition	10
Electronic emissions control	50
3-way catalyst	76
PCV	3
Fuel evaporation	15
EGR	37
Sensors	6
Total	$243

*1972 dollars

With the distinct possibility of the automobile markets containing two versions of the internal combustion engine (carbureted and fuel injection), Wankel engines (see Section 5), and possibly some Diesel engines (see Section 6), it became increasingly difficult for the Panel to deal with this proliferation. As an aid in this problem, a projection was made of a mix of engines that might be possible for 1976 (see Table 4). This projection, based on the judgment of the Panel, in turn, built on the preliminary design and production activity that the Panel observed on its visits.

This projection also served as an input constraint on the computer simulation the Panel used to assess the impact on manufacturing resources (see Section 9). This simulation included an estimate of sticker prices for the basic cars including standard accessories. The cost of equipment and tooling are included in these prices, and also capital investment costs (see Section 9). The events that must occur in 1973 for this projection to be realized are given in Table 5.

The important general observation from this projection is the extensive changes that may come in the industry over a very short period. Regardless of the exact outcome, the period from 1974 to 1977 should prove to be the most turbulent days for the industry since the 1918 to 1923 period.

Table 4

PROJECTED U.S. AUTOMOBILE SALES BY DOMESTIC[a] PRODUCTION IN 1976 (for basic cars with standard accessories)

	Sticker Price ($) (1972 dollars)	Volume (Cars)	Total
1. SUBCOMPACT			
IC - 4 cylinder	2,142.	100,000	
Wankel (1R)	2,059.	300,000	
			400,000
2. COMPACT			
IC - 6 cylinder	2,711.	200,000	
Diesel - 4 cylinder SC	2,731.	100,000	
Wankel(2R)	2,598.	400,000	
Stratified-Charge (4 cylinder)	3,200. (at ¼ million per year volume)	10,000	
			710,000
3. INTERMEDIATE (6)			
IC - 6 cylinder	3,131.	750,000	
Diesel - 6 cylinder SC	3,374.	100,000	
Wankel (2R)	2,839.	500,000	
			1,350,000
4. INTERMEDIATE (8)			
IC - V-8 - '76 NO_x	3,750.	1,500,000	
IC - V-8 - FI - EEC	3,418.	500,000	
Diesel - 6 cylinder SC	3,734.	10,000	
Wankel (2RH)	3,274.	25,000	
			2,035,000
5. STANDARD (8)			
IC - V-8 - '76 NO_x	4,000.	2,250,000	

Table 4 (cont'd)

	Sticker Price ($) (1972 dollars)	Volume (Cars)	Total
IC - V-8 - FI - [illegible]	3,818.	750,000	
Diesel - 6 cylinder SC	4,404.	10,000	
Wankel(2RH)	3,474.	25,000	
			3,035,000
6. STANDARD/Luxury			
IC - V-8 - '76 [illegible]	6,080.	1,500,000	
IC - V-8 - FI - REC	5,958.	500,000	
			2,000,000
7. LUXURY			
IC - V-8 - '76 [illegible]	8,230.	750,000	
IC - V-8 - FI - REC	8,158.	250,000	
			1,000,000
			10,530,000

*Includes Canadian production.

Table 5

Major Events that Must Occur in 1973 To Meet Panel's 1976 Projection

IC - V-8/'76 MCS

Freeze design for production
Build converter plant and line
Commit to plant and equipment for monolith
Commit to new carburetor production design
Freeze EFV design and revise head lines

IC - V-8/FI

Freeze design for production
Commit to pump and nozzle plants
Build low-volume production tooling and vehicles
Field test low-volume production vehicles
Commit to electronic emissions control unit plant and tooling

Diesel

Freeze design for production
Arrange for transfer of European light-duty Diesel technology
Build low-volume production tooling and vehicles
Plan for conversion of gasoline engine lines to Diesel
Plan body changes

Wankel

Freeze design for production
Order trochoid grinders and surface preparation equipment
Commit to high-volume plant and machine tools
Plan foundry conversion
Complete manufacturing development on automated assembly
Field test low-volume production units
Start body restyling

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5 WANKEL ENGINE STATUS FOR 1976 AND ASSOCIATED COSTS

The Wankel engine is being mass produced in Japan and sold in the United States at competitive prices. The engine is in mass production in Japan at Toyo Kogyo on what is reported to be an extremely modern line. American sales of the Mazda in the United States are projected at 350,000 units in 1975. With the prospect of such fast-growing competition, both General Motors (see below and Appendix IX) and Comotor (a European consortium, see Appendix VIII) are about to commit their designs to mass production. Since the Mazda is reported to have no undue emissions disadvantage, there is every indication that a substantial number of Wankel-powered automobiles will be driven on United States roads in 1976.

General Motors indicated to the Panel that they have not made a decision to go into production on the Wankel engine. They are working on various designs and have set up an experimental facility at the Willow Run transmission plant to develop manufacturing processes for each component and to build experimental engines for R/D testing. A recent announcement indicated a definite production commitment to the Wankel by General Motors, but, according to them, this is not correct.

The Panel visited the facility at Willow Run to confirm the manufacturing statements and to discuss the manufacturing problems with the design engineers and the manufacturing engineers. They have experimental tooling and equipment installed at this facility to study the various manufacturing processes to determine the best method and cost and the highest quality.

A firm design has not been specified by the design engineer group. General Motors stated that they have selected the Wankel engine for research and manufacturing development because of some inherent advantages. The Wankel engine is shorter and lighter than equivalent engines, so a front engine drive system can provide extra space for passengers and future safety features.

The engine is not an especially low-emission design, although

the NO_x emissions are lower than the equivalent horsepower reciprocating gasoline engine. The engine has a cost advantage due to its low weight per horsepower--approximately 1.5 lb per horsepower compared to 4 to 6 lb for a gasoline engine. Limited data are presently available on the long-term durability and reliability of the General Motors Wankel engine. The fuel consumption can be made competitive with the reciprocating engine. The manufacturing advantages of the Wankel engine are that it can be manufactured and assembled on fully-automatic production lines. The engine design will eventually require a new frame and body design that will have many safety, space, and weight advantages. The emissions control devices have not been developed, although there is a configuration using a thermal reactor, a catalytic converter, and electronic controls for the emissions designed by Mazda. The implementation plan for the General Motors Wankel engine has it introduced into the low end of the line, possibly replacing both the 4- and 6- cylinder engines in turn. The optimum-cost volume per year of the Wankel engine will be between 450,000 to 600,000 engines per year. The small V-8's might also find a competitor in a larger diameter 2-rotor Wankel engine as (designated 2RH in this report).

A 4-rotor Wankel engine is a more complex design with longer crank shaft. It is not likely to be a competitor to the V-8 until two to four more years have been spent on its development.

The manufacturing requirements for the Wankel engine are concentrated around the following significant equipment: a trochoid grinder for the rotor housing, a rotary grinder for finishing of the end housing, the eccentric grinder for the rotor, some special plating equipment combined with surface preparation equipment, and special equipment for pressing and sintering the apex seals. These machines are available today from several machine tool concerns and can be delivered within one or two years. Mass production conversions of these will require between one and two years of tooling design. An automatic assembly line and machining line combined will probably take anywhere from three to five years to develop and install. There is a possibility that the Japanese have developed conventional

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transfer line machinery for their current production. They may have also designed a fully automatic machining and assembly line for their new production plans.

The cost of the Wankel engine and car will be $140 to $900 less per car than the 1976 dual-catalyst configuration (see Table 8) of which $25 to $77 is in the engine and the rest of the saving comes from design of a lighter, shorter car configuration. We project that 1,200,000 cars will be powered by Wankel engines by 1976 (see Table 4). Further discussion will be presented in Section 9.

6 DIESEL ENGINE STATUS FOR 1976 AND ASSOCIATED COSTS

The Diesel engine, which grew up with the gasoline engine, has been most popular in the United States for trucks and stationary uses. By contrast, smaller Diesel engines are in wide use in England and Europe for taxicabs and light vans. These light engines are predominately of the precombustion chamber or indirect injection (IDI) type, as compared with the direct injection (DI) types common in trucks. The IDI Diesel engine, which has better combustion and smoke control potential, is the principal engine considered here for potential passenger-car use.

Several plants in England and Europe are currently mass producing small IDI Diesel engines for passenger cars. These include Perkins (England), Ford (England), and Daimler-Benz (Germany). At Daimler-Benz approximately one-third of their production, amounting to 300,000 Diesel engines, is made on transfer and assembly lines similar to those for their 4-cylinder gasoline engine. Approximately 6,000 of these cars were sold in the United States last year.

The cost per engine for these high-volume Diesel engines is comparable to but slightly higher than the cost of United States gasoline engines. The fuel-injection pumps and injection nozzles are made on very modern mass production equipment in England and in Germany. The costs of the fuel-injection system could be expected to be lowered from their current level if the United States were to add the light-duty Diesel engine to some of their production lines. The manufacturing know-how for the fuel-injection system and the light-duty Diesel is available in Europe and the technology can be transferred within one to two years. In fact, some engines could be delivered to the United States at competitive prices. The introduction of the Diesel to the car body would require major changes in the suspension, frame, and drive systems.

Daimler-Benz emphasized particularly that the proper emission test procedure for passenger-car Diesel engines is not clear. (The Clean Air Act Amendments are specific to gasoline engines.) They have requested clarification of the test procedure from EPA, but have not

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received an answer as yet.

It appears that a configuration suitable for 1976 might have most of the control built into the engine, with possibly a computer-controlled EGR system. The Diesel engine may not require a catalyst for either 1975 or 1976, nor will it require any air-injection system, but it will require some form of turbocharging, which is an air system itself. There are some disadvantages to the Diesel engine because of the higher pressures and higher temperatures, but these costs have to be compared to the added emission control devices required for 1976 cars. The Diesel engine has fuel economy advantages and a known record of low maintenance. The light-duty Diesel engine, however, has been designed for 4- to 6-cylinder passenger vehicle applications but a light-duty 8-cylinder engine does not exist for this application. An implementation plan for Diesel engines for the 1976 model year could only include that volume of car production now using 4- and 6-cylinder engines.

Much of the technology needed to put together this 1976 Diesel engine configuration is available, mostly in Europe, but it is scattered. For example, low-peak-pressure Diesel engines have been developed by McCulloch, and Diesel EGR systems have been developed for German mining use. Pump and injector technology is located primarily in England (CAV) and Germany (Bosch). Ricardo (England) is the major European consultant. This wide dispersion of technology is a major barrier to the coordinated development of a 1976 Diesel-engine configuration.

The main difficulties with the Diesel engine are noise, smoke, and odor. Noise levels reportedly can be reduced by suitable design. One of the major contributors to noise in the Mercedes Diesel engine is from the Bosch injection pump, which could be made quieter. Smoke reduction is attained by using an IDI engine and keeping the engine relatively lightly loaded. Odor control is a complex problem, currently under extensive study at A.D. Little, Inc. Some control can be attained by reducing the aromatic content of the Diesel fuel.

Present day Diesels have the advantage of long life, minimum maintenance, and fuel economy. The disadvantages of the Diesel are weight, size, and the creation of other undesirable air pollutant

characteristics not specified in the 1970 Clean Air Act, namely noise, odor, and particulates.

The cost of the Diesel engine relative to the 1976 dual-catalyst system configuration will be $10 to $35 more for the engine, and $50 to $160 more for the car (see Table 8). This is due to the added engine weight, which results in modifying the suspension, frame and body. The Panel's projected sales pattern for 1976 (Table 4) includes 220,000 Diesel-powered passenger vehicles. These are mostly in the middle-size range and include predominately work vehicles (taxis, fleet cars, government vehicles, etc.) and some private automobiles. As noted, this projection is considered possible, but optimistic. The main deterrent to the realization of this projection is the present lack of commitment by a major American auto company to a passenger-car Diesel. The specific commitments that must be made in 1973 to realize the Panel's projection are summarized in Table 5.

7 STRATIFIED-CHARGE ENGINE STATUS FOR 1976 AND ASSOCIATED COSTS

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The stratified-charge engine as developed by the Tank Automotive Command and Ford (PROCO) has had some low mileage emissions data very favorable to the 1976 standards.

The engine is a combined fuel-injection and spark-ignition system. It therefore has the added cost of two systems. The emissions hardware required for the 1976 configuration contains a thermal reactor, 2 monolith catalysts and a pellet catalyst, combined with EGR and air injection subsystems. All the fuel economy advantages and multi-fuel advantages of the stratified-charge engine are cancelled when this emission equipment is added.

The experimental 4-cylinder 1976 configurations are being made by TACOM as part of a government requirement for the MUTT vehicle. The Ford PROCO engine is an 8-cylinder V-8 that is in test. The stratified-charge engine has design features that have aided the other competitive engine manufacturers in their design research. The advantages of the stratified-charge as originally conceived are being adopted by the other competitive engines resulting in less difference in cost effectiveness.

The cost estimates for the stratified-charge engine are based on a mass-production environment; this engine would cost between $100 and $150 more per car over the 1976 dual-catalyst configuration (see Table 8). The investment required to produce the V-8 engine on a mass production basis at the rate of ½ million per year, would require a completely new facility at a total cost of $1.2 billion.

Our estimate is that there will be 10,000 4-cylinder stratified-charge engines sold in the United States in 1976. It should be noted that the U.S. Army has a $16 million design contract to improve the design characteristics using this principle. This work is being done at the Ordnance Depot, Detroit, Michigan.

Based on current technology, this modified engine is not likely to be widely accepted within the United States auto industry.

3 STATUS OF LIQUEFIED GAS SUBSTITUTES FOR GASOLINE

It is possible to modify the petroleum refining process so that LPG can be substituted for gasoline for motor vehicles, but the costs are very high. The capital costs will be in the $50 billion range. The fuel costs to the customer will be about twice as much as gasoline presently costs. There is a serious net loss of energy in changing from gasoline to liquid petroleum gas (LPG). The percentage of crude oil used in the processing operations will increase from about 4 percent to about 14 percent. This is an unrecoverable waste of natural resources.

There is not enough LPG, liquid natural gas (LNG), or synthetic natural gas (SNG) currently available to be significant if conversion to LPG were desired now. Simulation models are available for the conversion process. Although models are easy to use and the theory of high conversion percentages to LPG is well understood, there are many practical innovations that must be developed to reach the theoretical indications.

A three year lead-time for making changes for supplying alternative fuels is a minimum.

9 ESTIMATED IMPACT ON RESOURCES OF PANEL'S PROJECTED 1976 IMPLEMENTATION PLAN

The broad mission of the Panel was to evaluate technological feasibility of meeting the 1975-1976 light-duty vehicle emission standards from the producibility point of view. This was to include not only a consideration of the technical possibility of building promising low-emission engines, but also an evaluation of the costs involved. In previous sections of this report, producibility and costs of several individual engine types were discussed. As mentioned earlier, the American automobile producers are by and large seeking to meet the 1976 requirements with a carbureted piston engine across their car lines. It is considered likely by the Panel, however, that no single engine type will prove suitable for all sizes and types of automobiles, but probably several new low-emissions engine configurations will phase in to replace some of the carbureted piston engines now offered. The mix envisioned by the Panel was given in Table 4. Clearly, the phasing-in of the various new engines and the phasing-out of the engines they replace would have a major impact on the automobile industry. The Panel, using a simulation of the dynamics of the automobile industry, endeavored to estimate this impact. The main difficulty in determining the impact of this "mixed engine" strategy was the sheer size and complexity of the task. To make the simulation manageable, it was necessary to make the following assumptions:

1. The 1976 car configuration with the carbureted piston engine will be produced only in model years 1975 and 1976.
2. The Wankel engine will be introduced initially in the small cars (subcompact and compact) and subsequently will be developed in higher horsepower versions for larger vehicles.
3. Diesel engines (4 and 6 cylinders) will be introduced for fleet car usage by 1975. A V-8 Diesel will be introduced subsequently.
4. A limited number of 4-cylinder stratified-charge engines

will be produced for evaluation by the U.S. Army.

5. A V-8 gasoline engine with electronic fuel injection will be introduced by 1976.

The domestic production schedule resulting from these assumptions, consistent with the Panel's "mixed engine" projection for 1976, is shown in Table 6. The capital investment impact of this schedule on manufacturing facilities was then developed, as a sticker price increase, using the simulation model.

In the simulation model, the aggregate American production was considered without identifying the specific producer. The car configurations were detailed down to the major components and subassemblies. These units were then scheduled in production in the proper sequence and at the proper time to yield the desired schedule using standard industry leadtimes. Five engine types were used, and these were then combined into seven basic car configurations. The specific details of the simulation are given in Appendix XI. The price impact of the capital investment to attain the projected engine mix is summarized in Table 7. The first column contains the total anticipated capital investment in new production lines, old production line tearup, assembly-line changes and new facilities. The total capital investment is estimated as $6.23 billion, which would be spread over about 10 years. In the second column the estimated number of vehicles over which the investment would be amortized is given. These numbers were developed giving due consideration to expected product life and normal industry amortization practices. As can be seen in column 3, the expected sticker price increases to return this capital investment range from $8 to $150 per car.

To compare the relative retail price to the customer of the alternative engine types, the sticker prices of seven car configurations were developed by major cost element. These data, shown as Table 8, include the capital investment increments developed in Table 7 as the last row.

Table 6 Panel's Projected Production Schedule by Engine Type

Size and Code No.	Rotor or Cyl.	CID	HP	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Wankel														
Subcompact	1	102	120			50	100	300	500	700	700	800	800	800
Compact	2	204	150		50	50	250	400	400	400	400	500	750	750
Inter A	2	204	170			50	250	500	750	750	1250	1500	1500	1500
Inter B	2H	300	240					25	150	300	400	500	1500	2000
Standard	2H	300	240					25	150	300	400	500	1500	2000
Standard	4	408	300						50	150	250	250	500	1000
Luxury	4	408	400						50	150	250	250	500	500
Stratified Charge														
Subcompact	4		100											
Compact	4		120				2	10	10	15	20	25	25	25
Inter A	6		170											
Inter B	8		200						1	2	2	1		
Standard	8		250											
Std/Lux	8		270											
Luxury	8		300											

Table 6 (cont'd.)

Size and Code No.	Rotor or Cyl.	CID	HP	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Internal Combustion														
Subcompact	4	153	100				100	100	0					
Compact	6	200	140				400	200	0					
Inter A	6	250	160				1500	750	0					
Inter B	8	318	200				2000	1500	1000					
Standard	8	360	220				3000	2250	1500					
Std/Lux	8	402	250				2000	1500	1000					
Luxury	8	500	300				1000	750	500					
Diesel														
Subcompact	4						25	100	200	300	300	300	300	300
Compact	4		140				25	100	200	300	300	300	300	300
Inter A	6		160					10	25	50	50	100	200	200
Inter B	6		180					10	25	50	100	200	400	400
Standard	6		200								50	50	100	150
Std/Lux	8		200											
Luxury	8		240											

Table 6 (cont'd)

Size and Code No.	Rotor or Cyl.	CID	HP	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Fuel Injection IC														
Inter B	8	318	220					500	1000	1700	1600	1500	500	0
Standard	8	360	250					750	1500	2700	2600	2500	1500	1000
Std/Lux	8	402	300					500	1000	1750	1750	1750	1500	1000
Luxury	8	500	400					250	500	750	750	750	500	500

Table 7

Summary of Estimated Capital Investment by Engine Types

Engine Type	Cyl.	Estimated Total Investment Thousand $	Car Volume over Which the Investment Is Amortized in Thousands	Estimated Sticker Price Investment Penalty $ per Car
1976 Carbureted piston engine dual catalyst	4	66,880	3,000	22
	6	67,540	6,000	11
	8	709,600	24,000	30
1977 V-8 with fuel injection and feedback controls	8	325,000	40,600	8
Wankel	1 or 2R	530,000	16,150	39
	2 RH	1,600,000	21,750	74
	4 R	1,280,000	8,400	154
Diesel	4	56,300	1,825	31
	6	62,300	1,825	34
	8	97,000	1,970	49

Table 8

Development of Vehicle Prices by Engine Type

Table 8

Development of Vehicle Prices by Engine Type

Type of Engine	Carburetted Petrol Engine							Diesel							Petrol							Truck Subsection			
Class	4 cyl	4 cyl		6 cyl				4 cyl		6 cyl			8 cyl		1½	2½		3½		5½		6 cyl			
Body Type	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	4	5	6	7
Estimate																									
BASE																									
- Raw Materials	840	880	880	915	940	990	930	880	947	925	952	980	730	980	232	300	312	357	390	510	555	410	600	690	950
- Stamping Labor	125	135	150	150	160	160	175	125	135	150	150	160	160	175	135	135	190	150	160	160	175	190	190	190	175
- Parts and Labor	417	514	581	640	680	991	1,282	417	514	581	640	680	991	1,280	415	500	573	631	679	977	1,277	640	980	991	1,280
- Subtotal	782	999	1091	1,305	1,366	1,841	2,387	822	995	1,236	1,242	1,324	1,881	2,385	772	969	1,093	1,138	1,228	1,792	2,272	1,240	1,380	1,811	2,397
ENGINE																									
- Induction System Parts and Labor	86	86	86	107	110	110	110	109	30	30	30	33	33	33	33	86	86	86	94	89	90	90	90	73	73	90
- Other Systems Parts and Labor	110	155	176	213	237	315	442	126	255	255	323	330	344	460	380	805	152	173	188	191	193	170	250	260	323	427
- Subtotal	196	241	260	320	347	425	552	235	275	275	343	363	369	493	551	109	230	259	274	280	283	260	317	330	406	517
Total Body and Engine	978	1240	1351	1,625	1,693	2,266	2,939	1057	1271	1,439	1,585	1,739	2,329	2,966	901	1,167	1,396	1,482	1,565	2,169	2,737	1,521	1,662	2,167	2,914
Car & Engine Assembly	343	393	393	443	443	493	493	343	323	323	373	373	443	443	443	393	353	393	373	373	433	533	373	373	473	473
Total Car	1321	1593	1744	1,968	2,036	2,759	3,432	1398	1620	1,996	1,912	1,950	2,186	2,909	3,429	1344	1,500	1,667	1,775	1,800	2,602	3,170	1,894	2,035	2,720	3,387
Mark-Up	1.6	1.7	1.8	1.9	1.9	2.2	2.4	1.6	1.6	1.7	1.8	1.9	2.0	2.3	2.4	1.6	1.7	1.7	1.8	1.8	2.1	2.3	1.8	1.8	2.1	2.4
Basic Sticker Price	2130	2700	3140	3720	3970	4850	8290	2230	2270	2700	3360	3700	4370	6414	8250	2600	2530	2800	3180	3600	5450	7360	3410	3810	5950	8130
Optical Equipment	32	11	11	30	30	30	32	-	35	35	36	36	36	40	40	32	32	30	70	70	130	130	8	8	8	8
Sticker Price	2162	2711	3151	3750	4007	4880	8230	2250	2305	2735	3396	3736	4406	6463	8290	2632	2562	2830	3250	3670	5580	7490	3418	3818	5958	8138

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A comparison of the sticker prices in Table 8 indicates that the carbureted engine, the fuel-injection engine, and the Diesel engine are comparable in price for most car configurations and the Wankel engine is on the average about 8 percent less.

SUPPLEMENTAL REPORT ON

MANUFACTURABILITY AND COSTS OF PROPOSED LOW-EMISSION AUTOMOTIVE ENGINE SYSTEMS

by

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Prepared for the

COMMITTEE ON MOTOR VEHICLE EMISSIONS

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1. INTRODUCTION

As a result of the Committee on Motor Vehicle Emissions information about recent developments in emission systems for 1976 passenger cars, we have prepared a revised implementation plan using a new set of assumptions. We have also included a summary of the total costs to customers including capital equipment costs, maintenance costs, fuel penalty costs, and the vehicle sticker price values for each new configuration. These costs were related to a 1970 car configuration baseline, so that the costs per year for 1976 emission control devices can be defined as added costs to customer over a period of five years.

The manufacturing data that we obtained during our visits to Japanese automobile companies concerning Diesels, Wankels, and stratified-charge engines are included.

485 2. REVISED IMPLEMENTATION PLAN FOR MANUFACTURING AUTOMOBILES EQUIPPED WITH 1976 EMISSION CONTROL DEVICES

The new 1976 implementation plan will include the stratified-charge 3-valve engine developed by Honda and the electronic fuel injection system for 4- and 6-cylinder engines. The Wankel production plan was reduced to allow for stratified-charge and fuel-injection engine production in 1976 and thereafter. The 1976 dual-catalyst carbureted engine was replaced by the fuel-injection engines in 1976 to determine the impact on the fuel-injection systems manufacturing facilities.

Since fuel-injection systems are not manufactured in the United States in a mass-production environment, we had to assume that European production could be made available and that Bosch and CAV would provide technology for their U.S. licensees to manufacture in new U.S. facilities. Our data obtained from these manufacturers indicated that 8 to 9 million fuel-injection systems could be manufactured for 1976 emission systems since most of the companies stated that they could provide their share of the production within 18 to 24 months. Our assumption is based on data that four to six companies would provide facilities and tooling to meet the total production requirements. We recognized that the foreign facilities were also committed to increase production demands for fuel-injection systems in Europe.

The revised implementation plan used the following car configurations:

1976 Spark-ignition carbureted piston engines with dual catalyst

1976 Electronic fuel-injection piston engine with closed loop feedback system

1976 Light-duty diesel piston engine with EGR control system

1976 Wankel rotary engines with thermal reactors and catalysts and/or EGR

1976 Stratified-charge 3-valve piston engines using controlled EGR 49<

The volume mix will be based on the 1971 production data that put more emphasis on the smaller vehicles. The mix of car configurations and engine types with corresponding volume estimates is as follows:

Code No.	CID	Car Configuration	Engine	Production per year
1	153	Subcompact	4 cyl.	700,000
2	170-200	Compact	6 cyl	800,000
3	225-250	Intermediate A	6 cyl.	1,150,000
4	302-318	Intermediate B	8 cyl.	2,000,000
5	340-360	Standard	8 cyl.	3,000,000
6	383-402	Standard luxury	8 cyl.	2,000,000
7	426-500	Luxury	8 cyl.	1,000,000
				10,650,000

The increase of 650,000 cars over the original implementation plan is associated with a substantial increase of small vehicle production.

The product and resource data base with the corresponding product structures were revised to include the stratified-charge 3-valve, fuel-injection for 4- and 6-cylinder engines. The maintenance and fuel costs were also added to the data base for each car configuration.

As in the first implementation plan the resources (facilities and plants) were limited to those producing major assemblies and components.

The revised implementation schedule is based on the following set of assumptions:

1. The 1976 dual-catalyst carbureted piston engine will be produced in the last half of model year 1975 only.

2. Wankel engines will be introduced initially in small cars and subsequently will be developed in higher horsepower versions for

larger vehicles.

3. Diesel engines (4- and 6-cylinders) will be introduced for fleet car usage by 1975. The 4-cylinder engine will be used for body types 3, 4, and 5. The V-8 Diesel will be introduced subsequently for body types 6 and 7. It is recognized that equivalent horsepower and performance will not be achieved with these engines.

4. The stratified-charge 3-valve piston engine will be introduced in the 4- and 6-cylinder cars only. A V-8 version is assumed to take considerable engineering development and could not be made available in 1976.

5. Fuel-injection piston engines with electronic control subsystems for fuel, emissions, and feedback controls will be introduced in 4-, 6-, and 8-cylinder engines in 1976.

The revised Implementation Plan is displayed in Table 1 and the data for 1976 production are summarized in Table 2.

Table 1 Projected Production Schedule by Engine Type

Size and Code No.	Rotor or Cyl.	CID	HP	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Internal Combustion Dual Catalyst														
Subcompact	4	153	100	--	--	--	600	--	--	--	--	--	--	--
Compact	6	200	140	--	--	--	400	--	--	--	--	--	--	--
Inter A	6	250	160	--	--	--	1000	--	--	--	--	--	--	--
Inter B	8	318	200	--	--	--	1000	--	--	--	--	--	--	--
Standard	8	360	220	--	--	--	1500	--	--	--	--	--	--	--
Std/lux	8	402	250	--	--	--	1000	--	--	--	--	--	--	--
Luxury	8	500	300	--	--	--	500	--	--	--	--	--	--	--
							6000							
Diesel														
Subcompact	4	--	--	--	--	--	--	--	--	--	--	--	--	--
Compact	4	--	140	--	--	--	25	100	100	200	200	300	300	300
Inter A	6	--	160	--	--	--	25	100	100	200	200	300	300	300
Inter B	6	--	180	--	--	--	--	10	25	50	50	100	200	200
Standard	6	--	200	--	--	--	--	10	25	50	100	200	400	400
Std/Lux	8	--	200	--	--	--	--	--	--	--	50	50	100	150
Luxury	8	--	240	--	--	--	--	--	--	--	--	--	--	--
							50	220	250	500	600	950	1300	1350

TABLE 1 (continued)

Wankel														
Subcompact	1	102	100	--	--	50	100	300	300	400	400	600	600	600
Compact	2	204	150	--	50	50	250	300	300	300	300	300	500	500
Inter A	2	204	170	--	--	50	250	300	400	400	650	650	650	650
Inter B	2H	300	240	--	--	--	--	25	150	200	200	250	1000	1500
Standard	2H	300	240	--	--	--	--	25	150	200	200	250	1000	1500
Standard/lux	4	408	300	--	--	--	--	--	50	150	150	150	500	500
Luxury	4	408	400	--	--	--	--	--	50	150	150	150	500	500
					50	150	600	850	1300	1700	1950	2150	3650	5050
Stratified-Charge Honda 3-Valve														
Subcompact	4	153	70	--	--	--	--	200	200	200	200	250	250	350
Compact	6	200	120	--	--	--	--	200	200	200	200	300	300	300
Inter A	6	250	170	--	--	--	--	300	300	300	300	400	400	400
Inter B	8	318	200	--	--	--	--	--	--	--	--	--	--	--
Standard	8	360	250	--	--	--	--	--	--	--	--	--	--	--
Standard/lux	8	402	270	--	--	--	--	--	--	--	--	--	--	--
Luxury	8	500	300	--	--	--	--	--	--	--	--	--	--	--
								600	600	600	600	850	850	850

TABLE 1 (continued)

Fuel-Injection IC														
Subcompact	4	153	80	--	--	--	--	200	200	200	200	250	250	250
Compact	6	200	120	--	--	--	--	200	200	200	200	300	300	300
Inter A	6	250	150	--	--	--	--	450	450	450	450	550	550	550
Inter B	8	318	220	--	--	--	1000	2000	1750	1700	1600	750	500	--
Standard	8	360	250	--	--	--	1500	3000	2750	2700	2600	2000	1500	1000
Std/lux	8	402	300	--	--	--	1000	2000	2000	1750	1750	1500	1500	1000
Luxury	8	500	400	--	--	--	500	1000	1000	750	750	750	500	500
							4000	8850	8850	7750	7550	6650	5100	3600
							0	600	600	600	600	850	850	850
							600	850	1300	1700	1950	2750	3650	5050
							50	220	250	500	600	950	1300	1350
							6000	0	0	0	0	0	0	0
		Total Yearly Production				-	10650	10520	10500	10550	10700	10750	10900	10850

Table 2 Projected U.S. Automobile Sales by Domestic[a] Production in 1976 for Basic Cars with Standard Accessories

	Sticker Price (1972 dollars)	Volume(Cars)	Total
1. Subcompact			
Stratified Charge 3-Valve	2124	200,000	
Wankel (1R)	2059	300,000	
ZFI Fuel Injection	2096	200,000	700,000
2. Compact			
Diesel - 4 cylinder SC	2731	100,000	
Wankel (2R)	2598	300,000	
Stratified Charge (3-Valve)	2772	200,000	
EFI Fuel Injection	2670	200,000	800,000
3. Intermediate (6)			
Stratified Charge	2960	300,000	
Diesel - 6 cylinder SC	3374	100,000	
Wankel (2R)	2839	300,000	
EFI Fuel Injection	3097	450,000	1,150,000
4. Intermediate (8)			
IC - V-8 - FI - EEC	3418	2,000,000	
Diesel - 6 cylinder SC	3734	10,000	
Wankel (2RH)	3274	25,000	2,035,000
5. Standard (8)			
IC - V-8 - FI - EEC	3818	3,000,000	
Diesel - 6 cylinder SC	4404	10,000	
Wankel (2RH)	3474	25,000	3,035,000
6. Standard/luxury			
IC - V-8 - FI - EEC	5958	2,000,000	2,000,000
7. Luxury			
IC - V-8 - FI - EEC		1,000,000	1,000,000
			10,720,000

Note: This table is a revision of Table 4, Report of Panel on Manufacturing and Producibility.

[a]Includes Canadian Production.

3. MAINTENANCE AND FUEL COSTS FOR 1976 CAR CONFIGURATIONS AND THE RELATED COSTS TO A 1970 CAR CONFIGURATION BASELINE

The maintenance and fuel costs of the six engine types were found to be proportional to the number of the catalysts in the emission control system. Using the 1970 car configuration as the baseline we were able to develop relative maintenance and fuel costs.

The maintenance costs were developed by estimating the useful life of the emission-related devices and computing the replacement costs of the components that would be performed by the competent service centers. The useful life is defined as the expected life with 98 to 99 percent reliability. The catalysts were replaced at 20,000 miles so at least two changes were costed for 50,000-mile or 5-year duration. Other components such as filters and spark plugs were replaced according to automobile company standard maintenance practices. Each system was assumed to be 97 percent reliable with a 95 percent confidence level.

The maintenance reliability assumptions are

a. The 50,000-mile durability test procedure is the MTBF or the mean time before failure.

b. The 20,000-mile catalyst life is the assumed mission time with no expected failures within the 20,000 miles. The confidence limit is assumed to be 95 percent.

c. The average speed of the vehicle in use is 27 mph.

d. The hours in use are

1. MTBF = $\frac{50000}{27}$ = 1850 hours

2. Catalyst life = $\frac{20000}{27}$ = 740 hours

e. The system reliability is assumed to be 97 percent with a 95 percent confidence, and the components reliabilities for three system configurations are assumed to be as stated in Table 3.

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Table 3 Reliability or Maintainability of Emission Control Systems

System I -- 1976 Dual-Catalyst System with Carburetion

1	Carburetor (choke-altitude and temperature compensation	.99
2	Early fuel evaporation (Quick heat manifold)	.999
3	Air control valve	.999
4	Air injection pump	.998
5	Electronic ignition	.999
6	Exhaust gas recirculation	.99
7	Modified spark timing (TSC)	.999
8	NO_x reducing converter (2)	.98
9	HC/CO oxidizing converter	.98
10	PCV-valve	.98
11	Carbon canister	.99
12	Fuel-vapor separator	.999
13	Spark plugs	.999

System II -- EFI Closed Loop System for 1976

1	Throttle body	.999
2	Injector control	.99
3	Temperature control	.999
4	Pressure sensor	.999
5	Distributor	.99
6	EGR valve	.99
7	Ignition timing	.999
8	3-way catalyst (HC/CO and NO_x)	.98
9	Temperature sensor	.99
10	O_2 sensor	.99
11	ECU -- Electronic control unit	.995
12	Fuel pump	.999

13	Filter-fuel	.99
14	PCV valve	.999
15	Spark plugs	.999

System III -- Diesel--Fuel Injection 1975/1976 System

1	Fuel injection pump	.999
2	Nozzles (8--6--4)	.999
3	Fuel pump	.999
4	Fuel filter	.99
5	EGR	.98

The maintenance costs were developed for a typical configuration and then estimated for each engine and body combination. The costs were then related to the maintenance costs of the 1970 baseline car configuration.

The fuel costs are based on estimates and related information obtained from automobile companies in the United States, Europe, and Japan. Each engine type with the appropriate body was estimated using the basic data. Basic engines such as the Diesel and the stratified-charge engines have excellent fuel economy without emission devices, but as devices are added the fuel economy decays. The Wankel is not known to possess good fuel economy. As emission devices are added the fuel economy drops, but some of the fuel penalty is regained by the weight advantages of the engine and the appropriate body. The mileage of 12,000 miles per year was used to balance off the costs of catalytic converters, which were estimated to have a life of 20,000 miles. The fuel costs were based on $.40 per gallon for all types of fuels. We assumed that Diesel fuel costs would be increased by additional taxes if the Diesel engine became a high volume user for light-duty engines.

TABLE 4 VEHICLE MAINTENANCE COSTS

Stratified Charge - 3-Valve - Carbureted Engine

Related Emission Devices	System Cost	Freq.	Parts Cost	Labor Costs	Total Costs	5-Year Costs Maintenance
Air Cleaner	--	3	5.00	3.50	8.50	25.50
EGR system	--	4	--	7.00	7.00	28.00
Carburetors	--	2	3.50	10.50	14.00	28.00
Chokes	--	1	8.00	14.00	22.00	22.00
Valves	--	2	5.00	3.50	8.50	17.00
Distributor	--	3	3.00	7.00	10.00	30.00
Rotors	--	1	6.00	3.50	9.50	9.50
Plugs	--	3	9.60	3.50	13.10	39.30
Timing-spark	--	2	4.00	7.00	11.00	22.00
Fuel filter	--	1	1.50	--	1.50	1.50
PCV	--	2	2.00	1.50	3.40	7.00
Evap. controls	--	1	2.00	--	2.00	2.00
Total						232.00

Table 4 (Cont.)

VEHICLE MAINTENANCE COSTS
1976 Wankel Rotary Engine

Emissions Related Devices	System Cost	Freq.	Parts Cost	Labor Costs	Total Costs	5 Year Costs Maintenance
Air pump	30.00	0	--	--	--	--
Air controls	15.00	0	--	--	--	--
Air cleaner	--	3	5.00	3.50	8.50	25.50
EGR system	--	4	--	7.00	7.00	28.00
Carburetor	--	1	3.50	10.50	14.00	14.00
Chokes	--	2	2.00	14.00	16.00	32.00
Valves	--	2	5.00	3.50	8.50	17.00
Distributor	--	1	6.00	5.00	11.00	11.00
Points	--	1	3.00	7.00	10.00	20.00
Timing spark	--	1	4.00	7.00	11.00	11.00
Fuel filter	--	1	1.50	--	1.50	1.50
Thermal reactor (liners)	--	2	47.00	7.00	54.00	108.00
Converter	--	2	24.00	7.00	31.00	62.00
PCV valve	--	2	2.00	1.50	3.50	7.00
Evaporative controls	--	2	--	1.00	1.00	2.00
Spark plugs	--	3	6.40	3.00	9.40	28.20
Total						367.50

Table 4 (Cont.)

VEHICLE MAINTENANCE COSTS

1976 NO_x Dual-Catalyst Carbureted Engine

Emission Related Devices	System Cost	Freq.	Parts Cost	Labor Costs	Total Costs	5 Year Costs Maintenance
Air pump	30.00	0	--	--	--	--
Air controls	15.00	0	--	--	--	--
Air cleaner	5.00	3	5.00	3.50	8.50	25.50
EGR system	--	4	--	7.00	7.00	28.00
Carburetor	--	1	3.50	10.50	--	14.00
Choke	--	4	2.00	14.00	16.00	48.00
Valves	--	4	5.00	3.50	8.50	34.00
Distributer	--	1	6.00	5.00	11.00	11.00
Points	--	3	3.00	7.00	10.00	30.00
Timing-spark	--	2	4.00	7.00	11.00	22.00
Fuel filter	--	1	1.50	--	1.50	1.50
Monolith Converters	--	2	48.00	14.00	62.00	124.00
Pellet Converter	--	2	12.00	7.00	19.00	38.00
PCV valve	--	2	2.00	1.50	3.50	7.00
Evaporative controls	--	2	--	1.00	1.00	2.00
Spark plugs	--	3	12.80	3.40	16.30	48.90
Total						453.90

Table 4 (Cont.)

VEHICLE MAINTENANCE COSTS

EFI Electronic Fuel Injection -- Closed Loop Emissions Controls

Emission Related Device	System Cost	Freq.	Parts Costs	Labor Costs	Total Costs	5 Year Costs Maintenance
Throttle body	30.00	0	--	--	--	--
Fuel-injection nozzles	$2 x 8 = 16.00	1	16.00	7.00	23.00	23.00
Distributor	10.00	4	3.00	7.00	11.00	44.00
Spark plugs	8 x 1.60	3	12,80	3.40	16.30	48.90
EGR valve	7.00	4	--	7.00	7.00	28.00
Temperature valve	3.00	0	--	--	--	--
Air cleaner	--	3	5.00	3.50	8.50	25.50
Intake Manifold Pressure Sensor	3.00	0	--	--	--	--
Transmission signal	4.00	0	--	--	--	--
Electronic control unit	50.00	0	--	--	--	--
Fuel pump	12.00	0	--	--	--	--
Fuel evaporation	15.00	0	1.00	--	--	2.00
Fuel filter	7.00	4	7.00	1.00	8.00	32.00
PC valve	2.00	2	2.00	1.00	3.00	6.00
3-Way catalyst	76.00	2	12.00	7.00	19.00	38.00
O_2 sensor	6.00	2	6.00	1.00	7.00	14.00
Total						261.40

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TABLE 5 MAINTENANCE AND FUEL COSTS OF EMISSION SYSTEMS (1970 Car Baseline)

Car and Engine Type	Cylinder	Body	Year Maintenance Total	Baseline Maintenance	Hardware	Tooling, Design, and Weight Penalty	Fuel Costs/Year Total	Fuel Penalty	Sticker Price	Hardware Penalty	Weight and Design Penalty	Sticker Price Penalty
1970 baseline	4	1	36	0	16	-	200	0	1960	0	0	0
	6	2	40	0	17	-	220	0	2545	0	0	0
	6	3	40	0	17	-	255	0	2802	0	0	0
	8	4	44	0	18	-	285	0	3332	0	0	0
	8	5	44	0	18	-	350	0	3557	0	0	0
	8	6	52	0	22	-	380	0	5696	0	0	0
	8	7	52	0	24	-	400	0	7805	0	0	0
1976 NO_x dual catalyst	4	1	72	36	138	44	255	55	2142	122	22	182
	6	2	80	40	146	20	285	65	2711	129	9	166
	6	3	80	40	155	295	340	85	3252	138	284	450
	8	4	88	44	204	214	400	115	3750	186	184	418
	8	5	88	44	208	235	480	130	4000	190	205	443
	8	6	104	52	242	142	536	156	6080	220	112	384
	8	7	104	52	264	281	600	200	8350	240	251	545

Table 5 (Cont.)

Car and Engine Type	Cylinder	Body	Year Maintenance Total	Baseline Maintenance	Hardware	Tooling Design and Weight Penalty	Fuel Costs/Year Total	Fuel Penalty	Sticker Price	Hardware Penalty	Weight and Design Penalty	Sticker Price Penalty
1976 Diesel	4	1	26	-10	32	309	160	-40	2301	16	278	341
	4	2	26	-14	34	111	160	-60	2690	17	80	145
	6	3	31	- 9	36	536	180	-75	3374	19	502	572
	6	4	31	-13	44	358	200	-85	3734	26	324	402
	6	5	31	-13	46	801	230	-120	4404	28	767	847
	8	6	43	- 9	52	798	260	-120	6546	30	749	850
	8	7	43	- 9	55	659	280	-120	8519	31	610	714
1976 Wankel	1 or 2R	1	62	26	137	-38	240	40	2059	121	-77	99
	2R	2	68	28	146	-101	300	80	2590	129	-141	45
	2R	3	68	28	146	-109	340	85	2839	129	-148	37
	2RH	4	74	30	154	-354	400	115	3132	136	-428	-200
	2RH	5	74	30	160	-243	470	120	3474	142	-317	-83
	4R	6	88	36	187	-279	560	180	5604	165	-433	-92
	4R	7	88	36	205	-545	580	180	7465	181	-699	-340

Table 5 (Cont.)

Car and Engine Type	Cylinder	Body	Year Maintenance Total	Baseline Maintenance	Hardware	Tooling Design and Weight Penalty	Fuel Costs/Year Total	Fuel Penalty	Sticker Price	Hardware Penalty	Weight and Design Penalty	Sticker Price Penalty
1976 EFI-electronic closed loop	4	1	40	4	90	46	220	20	2096	74	38	136
	6	2	45	5	95	30	240	20	2670	78	22	125
	6	3	45	5	101	174	280	25	3077	84	166	275
	8	4	49	5	126	40	315	30	3498	108	32	166
	8	5	49	5	149	112	380	30	3818	131	104	261
	8	6	55	3	161	111	420	40	5968	139	103	272
	8	7	55	3	240	113	440	40	8158	216	105	353
1976 Stratified-charge 3-valve	4	1	48	12	105	59	220	20	2124	89	29	164
	6	2	50	10	116	111	240	20	2772	99	81	227
	6	3	50	10	118	40	280	25	2960	101	10	158
1976 Stratified-charge TACOM	4	1	84	48	175	125	227	27	2260	159	95	300

4. COST OF EMISSION CONTROL DEVICES FOR 1976 CAR CONFIGURATIONS AND THE RELATED COSTS TO A 1970 CAR CONFIGURATION BASELINE

Our objective to determine the costs per year to car owners was based on the following criteria:

1. Emissions hardware sticker price value
2. Weight or design penalty resulting
3. Capital cost amortization for equipment, tooling, and facilities
4. Emissions related maintenance costs for the 1976 configurations
5. Fuel costs penalty for emissions control devices
6. Total costs per year over 5 years.

The costs per year over 5 years to the customer are presented in Table 6.

The costs of each car configuration are based on the following criteria:

1. OEM (original equipment manufacturer) costs supplied to us by some vendors to the automobile industry. These costs were based on assumptions that the vendor would provide one-fifth to one-fourth the yearly production in 1976 and thereafter.
2. Automobile parts suppliers and warehouse price and cost data for engine components.
3. Dealer sticker price data for various components that are part of the total price of the car.
4. Standard estimating data used for mass-produced products. These data are based on costs per pound for various classes of products such as stampings, engine cast-iron components, engine steel-forging components and die-casting components such as carburetors.

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Table 6 Costs per Year over 5 Years to the Customer

	4 cyl.	6 cyl.		8 cyl.			
Car Configuration	1	2	3	4	5	6	7
1976 NO_x dual catalyst	127	138	215	243	263	285	361
1976 Diesel--EGR	18	-45	30	-18	36	41	14
1976 Wankel	86	117	120	105	133	198	148
1976 Stratified-charge 3-valve	65	77	67	--	--	--	--
1976 Electronic fuel injection with closed loop	51	50	85	68	87	97	114

The Diesel 4 cyl. is used in body type 2 and the 6 cyl. is used in the body type 4.

The costs are 1972 dollars and are sticker price value.

5. The automotive industry selling price to the dealers is called the warehouse selling price. By using the markup formula supplied to us by the automobile companies we could check our total estimates by working backward from the warehouse selling price.

Using these criteria we developed the major assembly and components costs for each car configuration. The cost data base contains costs for 2400 components, each chained to the appropriate body and engine. The total costs of the car are developed from summarizing the detail costs.

The labor costs of engine and car assembly are developed from using manning data obtained for typical plants. The labor costs include direct and indirect personnel.

We realize that the automobile manufacturers use a direct costing system that develops all the costs to produce a specific major product such as engine blocks, heads, and transmissions where major equipment and support costs are involved. Since these capital and support costs are often in the millions of dollars the product costs associated with these investments are volume-sensitive. Our costs are based on production volumes of 200,000 to 400,000 cars per year of a given model engine and body combination. If a given car configuration production volume per year was less than 200,000 we assumed that this car would be produced in combination with the next similar size vehicle.

Table 8 details the total costs to customer by engine type and by body size. The vehicle costs include the following:

Body Costs

a. Raw materials
b. Stamping labor for components
c. Parts costs for OEM components

Engine Costs

a. Emission system parts--OEM costs
b. Other engine component costs

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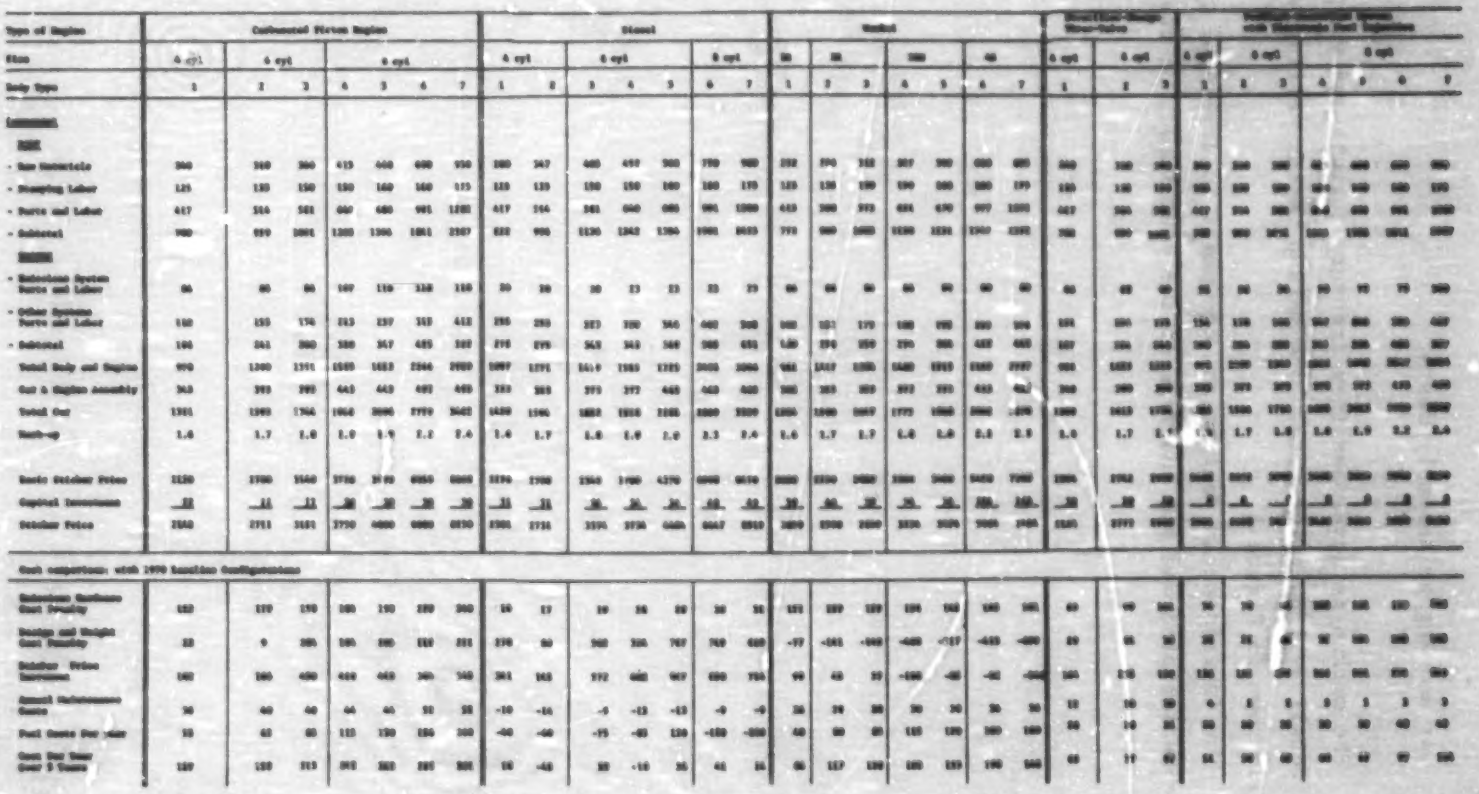
Table 7 Car Configuration Baseline Costs

(1972 dollars)

	1970 Carbureted Piston Engine Baseline						
	4 cyl.	6 cyl.		8 cyl.			
	1	2	3	4	5	6	7
Body							
Raw materials	240	310	360	415	440	690	930
Stamping labor	125	135	150	150	160	160	175
Parts and labor	417	514	581	640	686	991	1282
Subtotal	782	959	1091	1205	1306	1841	2387
Engine							
Emission system parts and labor	10	10	10	10	10	10	10
Other system parts and labor	110	155	174	213	237	315	412
Subtotal	120	165	184	223	247	325	422
Total engine and body	902	1124	1275	1428	1553	2166	2809
Car and engine assembly	323	373	373	423	423	423	443
Total car	1225	1497	1648	1851	1976	2589	3252
Markup	1.6	1.7	1.7	1.8	1.8	2.2	2.4
Basic sticker price	1960	2545	2802	3232	3557	5696	7805
Capital equip. and tools	0	0	0	0	0	0	0
Sticker price	1960	2545	2802	3332	3557	5696	7805
Maintenance/year	36	40	40	44	44	52	52
Fuel costs/year	200	220	255	285	350	400	460

Table 8 Breakdown of Total Cost to Customer of 1976 Configurations



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Car and Engine Assembly Costs

The markup is developed from industry formula and warehouse versus retail selling price data. The markup versus selling price curve is shown in Figure 1.

The investment in tooling and equipment is developed from the implementation plan and the analysis of the cost impact on resources.

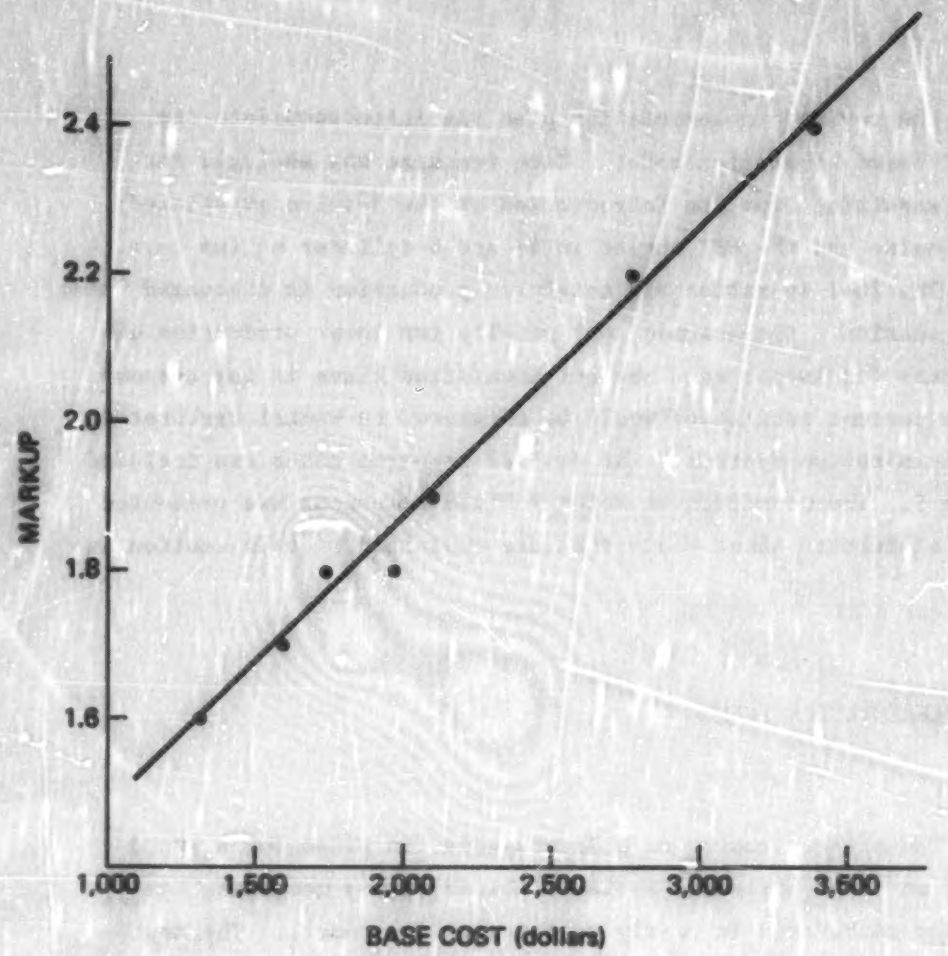

FIGURE 1 Relationship of markup to base cost of car.

5. COST OF RESOURCES RESULTING FROM THE IMPACT OF THE MODEL MIX IMPLEMENTATION PLAN

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The revised implementation plan was introduced into the computer-based simulation model. Each resource was analyzed for changes resulting from the introduction of the 3-valve stratified-charge engine and the EFI engine in 4- and 6-cylinder engine cars.

The fuel injection and catalytic production is discussed later in this section. The assumed cost penalty for lower production of carburetors for larger cars was not identified since it was assumed that the current facilities would be converted to Wankel carburetors and fuel-injection systems. The revised resource costs are included in Table 9. The Committee on Motor Vehicle Emissions has presented certain statements about costs that are explained in this section in detail.

CMVE IMPLEMENTATION PLAN

The present course of U.S. companies in proposing a HC/CO catalyst and a NO_x catalyst system combined with a mechanically controlled carburetor is costly to the user (customer). The costs elements are summarized as follows:

A. Hardware costs. The dual-catalyst system involves
   1. Air injection subsystem
   2. Carburetor system
   3. EGR - subsystem
   4. HC/CO - catalyst converter
   5. NO_x - catalyst converters (2)
   6. EFV - early fuel vaporization

B. Resource costs. The dual-catalyst system involves the following:

TABLE 9 SUMMARY OF ESTIMATED CAPITAL EQUIPMENT AND TOOLING INVESTMENT BY ENGINE TYPES

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Engine Type	Cyl.	Estimated Total Capital Equipment Investment (Thousand $)	Car Volume over which the Investment is Amortized (Thousands)	Estimated Sticker Price Investment Penalty ($ per car)
1976 carbureted Piston Engine	4	66,880	3,000	22
	6	67,540	6,000	11
	8	70,960	24,000	30
1977 V-8 electronic fuel injection	4	12,400	1,550	8
	6	34,000	4,250	8
	8	325,000	40,600	8
Wankel	1 or 2 R	630,000	16,150	39
	2 RH	1,600,000	21,750	74
	4 R	1,280,000	8,400	154
Diesel	4	56,300	1,825	31
	6	62,300	1,825	34
	8	97,000	1,970	49
Stratified charge 3-valve engine	4	49,500	1,650	30
	6	168,000	5,600	30

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1. Air pump manufacturing--expansion and duplication of current manufacturing facilities.

2. Carburetor--expansion of manufacturing to provide for complex carburetors (174 parts and 32 subassemblies - see Apache)

3. EGR--controls involve establishing vendors to produce the variety of valves to fit the varieties of engines

C. The HC/CO catalyst involves

1. Manufacturing containers in a mass-production environment similar to air cleaner and oil filter automated facilities. These will have to be designed and built within a two-year lead-time.

2. Manufacturing substrates for monolith or pellet production currently used for petroleum industry manufacturing. No mass production facility exists for producing monolithic substrates. The capability exists in batch production but a low-cost mass-production facility has to be produced in the next two years.

D. The NO_x catalyst involves

1. Manufacturing the containers for pellet-type design converters. These containers can be combined with the production facilities for HC/CO converters. The combined production for new cars will be 30 million per year, and, with two changes per 5 years, if the entire container is replaced, the yearly production will be 60 million per year by 1984-1985. If the container is not replaced but the pellets are replaced then the volume of pellets could be

a. 30 million x 6 lb = 180 million pounds of pellets if all three converters are the pellet type

b. Yearly pellet production for NO_x converters

1. 10 million x 6 lb = 60 million lb
2. Replacement (2) = 120 million lb
3. NO_x pellet total 1984 = 180 million lb

c. Monolithic converter production per year

1. Monolithic replacement = 20 million units
2. Replacement monolith (2) = 40 million units
3. HC/CO monolith production by 1980 = 60 million units
4. HC/CO monolith production by 1984 = 120 million units

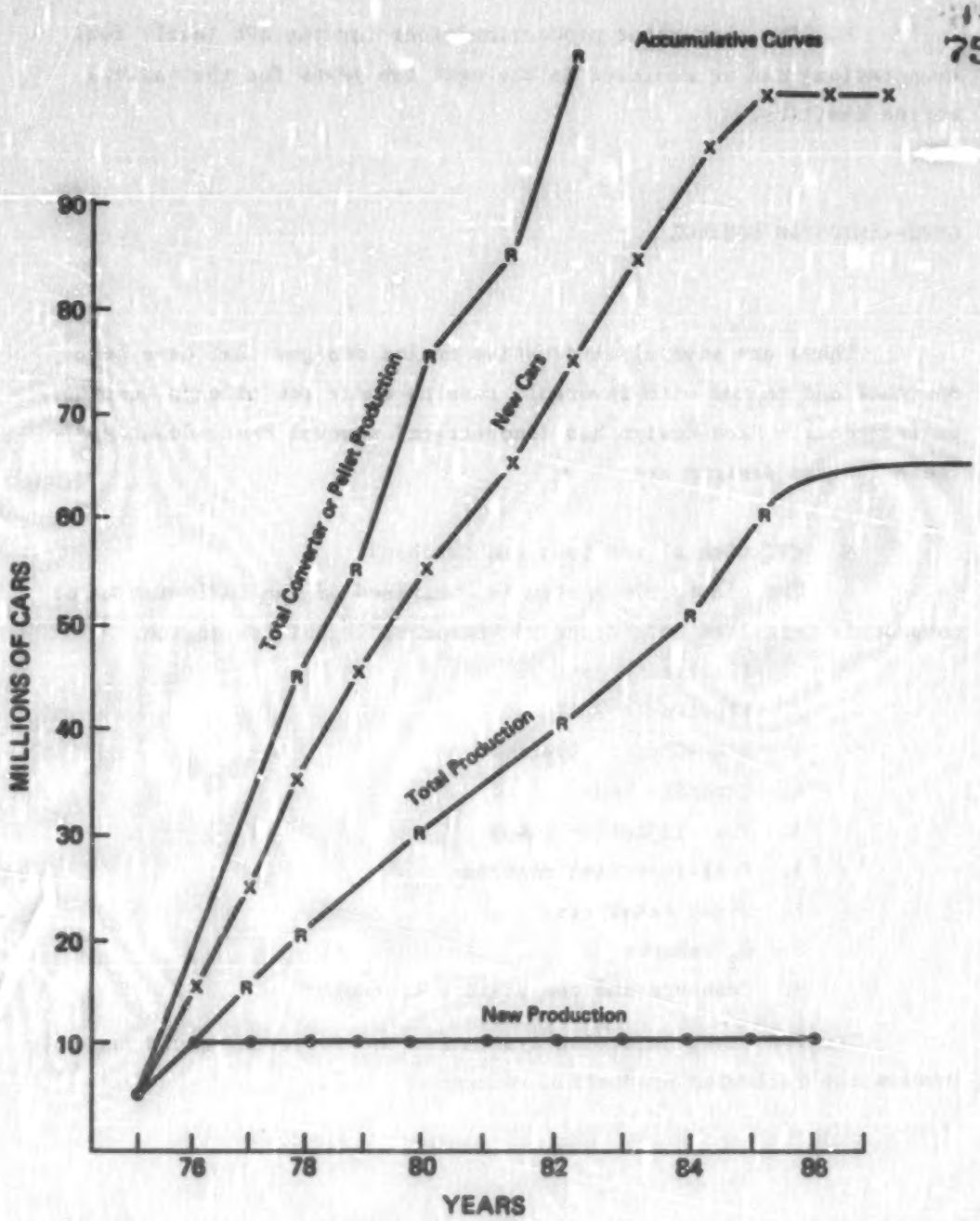

FIGURE 2 Pellet production in millions of units--one unit per car.

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E. The carburetor production plans for the EFE (early fuel evaporation) can be achieved in the next two years for the various engine families.

CMVE--EMISSION CONTROL

There are several alternative engine designs that have been designed and tested with favorable results under low mileage testing environments. Each design has demonstrated several cost advantages. These various designs are

A. EFI with closed loop and feedback

The electronic system is comprised of the following major components installed on a standard reciprocating piston engine.

1. Electronic control
2. Electronic ignition
3. EGR--Control system
4. Throttle body
5. Fuel-injection pumps
6. Fuel-injection nozzles
7. 3-way catalysts
8. O_2 sensors
9. Pressure and temperature controls

The 1976 fuel-injection system for the following would probably involve the following production volume:

		Vol/yr (Thousands)	No. of Designs
Subcompact	4 cyl.	200	2
Compact	6 cyl.	200	4
Intermediate	6 cyl.	450	4
Intermediate	8 cyl.	2000	4
Standard	8 cyl.	3000	4
Std/lux.	8 cyl.	2000	3
Luxury	8 cyl.	1000	3
Total EFI projected volume		8850	24 (for 1976)

The EFI systems would probably involve several designs: a minimum of 24 designs that have to be tuned to each engine configuration.

Production Status:

a. The 4-cylinder Bendix System is planned for June 1974

b. The 6-cylinder Bendix Systems would take 4 months for development and 5 months for test. June 1974 is the earliest start date. Tooling would require 12 to 18 months' lead time.

c. The V-8 design does not exist in the United States. A development phase of one year will be required during which the 14 V-8 engine designs could be tuned. The tooling could be ordered during this phase. The testing and certification that would follow production for V-8 could start in June 1974 to be in mass production by June 1975.

Assuming that the catalyst would be developed, tested, and certified during this period the following companies could share the volume:

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	1974	1975	1976
Bendix	200	800	2,800
Stanadyne (CAV)	50	200	500
Bosch (U.S.A.)	50	100	200
General Motors	250	1000	2,350
CAV (England)	200	750	1,500
Bosch (Germany)	200	750	1,500
			8,850

B. The Wankel engine is presently being produced in volume in Japan by Toyo Kogyo and prototypes are being developed by General Motors in the United States and by Comotor in Saar, Germany. The Toyo Kogyo production will total 850,000 2-rotor engines by 1975; 350,000 will be exported to the United States in Mazdas. General Motors-USA is likely to produce between 200 to 500,000 Wankels between 1974 and 1977. Wankel engines will probably be purchased from Comotor and installed in some U.S. company automobiles.

C. The Honda 3-valve engine is in the prototype stage at present. The production changeovers will involve a new head line, a new cam shaft line, and expansions in valve and carburetor production lines. The U.S. volume is small at this time unless a U.S. company adopts the 3-valve design for emissions control. If a U.S. company adopts the design, the changeovers or impact on current facilities will be significant but could be accomplished for some 1976 models.

6. JAPANESE AUTOMOBILE COMPANIES EMISSION CONTROL SYSTEMS PLANNED FOR MANUFACTURE IN 1975 AND 1976

In general the Japanese companies have not progressed as far as U.S. companies in their manufacturing planning of 1976 emission control devices. We were unable to obtain any time-phased production plans such as PERT or GANTT charts.

The facilities at Toyota and Nissan were modern mass production manufacturing units producing at rates equivalent to the United States. The Toyo-Kogyo new facilities were under construction. The older facilities were not comparable to Toyota. We were not allowed to visit the Wankel production facility so we spent most of our time discussing their capability of producing 1976 emission systems. Their current plans are to produce 80,000 Wankels per month in a 2-rotor version. There were no plans to produce a higher horsepower Wankel or to produce engines with 4-rotors such as developed by Mercedes Benz.

The Izusu light-duty facility is producing engines for General Motors. The capability exists to expand production if required, but no plans to expand existed at the time of our visit.

Japanese manufacturers were able to produce all the planned emission devices such as thermal reactors, converters, and catalysts in Japan using their own resources on the licenses from the United States for Europe. Most of the machine tools used to produce emission devices could be delivered from Japanese machine tool builders.